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TRANSFER OF PERCEPTUAL ADAPTATION TO SPACE SICKNESS: WHAT ENHANCES AN INDIVIDUAL'S ABILITY TO ADAPT?

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INTRODUCTION

The objectives of this project were to explore systematically the determiners of transfer of perceptual adaptation as these principles might apply to the space adaptation syndrome. The perceptual experience of an astronaut exposed to the altered gravitational forces involved in spaceflight shares much: 1) with that of the subject exposed in laboratory experiments to optically induced visual rearrangement with tilt (Witkin, 1949) and dynamic motion illusions such as vection (Dichgans & Brandt, 1978); and 2) experiences and symptoms reported by the trainee who is exposed to the compellingly realistic visual imagery of flight simulators (Kennedy, Lilienthal, Berbaum, Baltzley & McCauley, 1989) and virtual reality systems (Lampton, Bliss, & Knerr, 1993). In both of these cases the observer is confronted with a variety of inter- and intrasensory conflicts that initially disrupt perception, as well as behavior, and also produce symptoms of motion sickness.

While in both earth-bound and spaceflight conditions, the experience of all motion sickness-like symptoms is dispiriting, the plasticity of the human central nervous system also affords the opportunity for adaptation. This adaptation generally results in a reduction or elimination of the unpleasant symptoms while the observer remains in the environment, although post effects may occur upon egress and re-adaptation upon re-entry to the environment may be required.

Thus, overcoming these motion sickness symptoms, correcting performatory behavior and regaining normal perception when in a spacecraft may involve many of the same processes as adaptation to other forms of visual rearrangement (cf. Welch, 1978; Berbaum, Kennedy, Welch & Brannan, 1985; for reviews). The apparent similarity of the processes involved in overcoming the "space adaptation syndrome", on the one hand, and experimentally imposed dynamic perceptual rearrangements, on the other, implies similar processes at the central nervous system level. Also, it is known that some persons are better able to adapt to perceptual rearrangements in general. Measuring such an illusive phenomenon as "learning to learn" (Woodrow, 1939, 1946) is fraught with difficulties, but is not expected to be insurmountable.

The original purpose of the present effort was to explore the principles which govern transfer of perceptual adaptation by conducting a series of experiments in which perceptual adaptations were created and measured; particularly in cases where weak and non-debilitating nauseogenic stimuli may be practiced in order to afford some immunity from the stimulus conditions which produce motion sickness. In the experimental effort the plan was for "...exposing subjects to different visual distortions..." and it was "...predicted that exposure to one stimulus condition would afford some advantage for exposure to a second stimulus condition..." (p. C-5 SOW, 1 June 1989). The original plan called for the use of mirrors or distorting prisms, but the contract took a sufficiently long time to be put in place that we were able to assemble a vection drum prior to award, and so the first experiment capitalized on that availability since results from a vection drum experiment could be expected to provide direct application to the on-going plans (at that time) for acquisition of a Pre-flight Adaptation Trainer (PAT).

We proposed to conduct Experiment 1 first and intended to carry out additional experiments after completion of Experiment 1 since they would be based on the outcome of the first study. Specifically, it was to be determined whether, by means of extended training in perceptually rearranged environments, separated by periods of normal vision, human subjects can acquire specific and generalized adaptation sets to sensory conflicts. To achieve this goal, the present effort entailed: (a) an empirical study of transfer functions between visually induced illusion of self-motion such as may be experienced in perceptual adaptation trainers; (b) empirical study of time-course and longevity of perceptual adaptations which may occur; (c) whether and to what extent individuals differ in symptoms they experience during such experiences; (d) analysis of similar symptomatologic data obtained in connection with simulated flights in fixed and moving base military flight trainers which occasion profiles of motion sickness which resemble space adaptation syndrome including the after effects of postural disequilibrium; and (e) a literature review to provide identification and definition of the processes involved in perceptual learning. After initial contract award, funding was cut 50% for the first period of performance and was always 60% of the planned amount.

Progress in connection with the planned purpose was provided in several areas. Experiment 1 was in two parts. First a preliminary or pilot study was conducted to serve as a screening study to establish a full range of stimulus parameters and also to work out the necessary "language" and "definitions" of different perceptual experiences. Then the formal part of Experiment 1 was carried out using 30 subjects over five days (or sessions). The five repeated measures were used to determine the effects of adaptation, if any, on the main stimulus parameters. The full range of velocities over which humans are capable of experiencing the perception of vection were employed. Higher speeds were seen as fusion and lower speeds were confused with stationarity. In this study transfer of training would have been evident in changes in latency, saturation and slope of the vection psychophysical functions. Because there were five exposures spaced approximately one day apart it was possible to examine the time-course effects of repeated exposures close together. In this experiment we also attempted to determine whether some individuals adapted differently than others.

These results have relevance to the design and utilization of NASA's Preflight Adaptation Trainer (PAT) in that they illuminate the relatively stable psychometric properties of a phenomenon known to induce symptoms of motion sickness in stationary individuals. A principle goal of the PAT is to promote adaptation to Space Adaptation Syndrome (SAS) by exposing astronauts to conditions conducive to the development of motion sickness symptomatology in a terrestrial environment. The vection illusion may hold an important key to the successful implementation of the PAT. This experiment is reported completely in Section I below.

There are indications that these characteristics are likely to be stable, and this finding is encouraging since it suggests we may now begin to identify the stimulus factors that control the phenomena in order to reliably produce it. The ability to produce the vection illusion may prove to be critical to the goals of the PAT in that it is a known precursor of motion sickness in fixed-base simulators (Hettinger, Berbaum, Kennedy, Dunlap, & Nolan, 1990). This suggests it may now be possible to use the stability of the vection threshold and transfer function data as a way of equating individuals in perceptual adaptation studies. It is well known that cross-coupled angular accelerations (often involving gyroscopic torques in the semicircular canals) can produce symptoms of motion sickness and in one form or another such stimulation is used in laboratories in tests of motion sickness susceptibility (Kennedy, Berbaum, Williams, Brannan & Welch, 1987) . "Coriolis" (and sometimes Purkinje) is the term usually applied (Bensen & Bodin, 1966) to refer to these cross-coupled accelerations (and their effects). During vection it has also been reported that a form of Coriolis experience occurs (called pseudo-Coriolis [Dichgans & Brandt, 1973] since it occurs in the absence of a physical rotatory motion). Motion sickness is reported during these experiences. As with motion sickness induced by Coriolis stimuli and with space sickness, the pseudo-Coriolis symptoms diminish with repeated exposure and adaptation permits increased tolerance to subsequent exposures. Arguably such a set of stimuli could serve as a model in which to examine the perceptual adaptation process to motion sickness from all causes. Following this logic, now that we have demonstrated the stability and reliability of the simple vection stimuli, subsequent experiments would employ pseudo-Coriolis produced in a vection drum to determine the individual differences in adaptation as well as the rules for transfer of perceptual adaptation (acquisition, saving, extinction, transfer of training, generalization, etc.).

In addition to the experimental work we also used data collected on symptomatology check lists from several thousand exposures in fixed and moving base military flight trainers which occasion profiles of motion sickness which resemble space adaptation syndrome (including the after effects of postural disequilibrium). A scoring procedure was developed and simulator sickness data were analyzed. From this analysis, a diagnostic classification was modified to be employed in subsequent vection experiments. A more complete description of the methodology and examples of the work carried out under this contract appears below. These findings have subsequently been picked up by NASA scientists and others to evaluate simulator sickness, space sickness and virtual reality sickness.

<u>Profile Analysis of simulator sickness applied to space adaptation syndrome.</u> In motion sickness studies that we have conducted at sea, in aircraft, in simulators, during weightlessness, and on Slow Rotation Rooms, we have always measured diverse symptomatology through the use of a Motion Sickness Questionnaire (MSQ) checklist.

This MSQ was factor analyzed (Lane & Kennedy, 1988) and from this a new scoring key was developed. In that analysis, three factors emerged and these three symptom clusters have been used to form three MSQ subscales. These subscales or dimensions appear to operate through different "target" systems in the human to produce undesirable symptoms. Scores on the <u>Nausea</u> (N) subscale are based on the report of symptoms which relate to gastrointestinal distress such as nausea, stomach awareness, salivation, and burping. Scores on the <u>Visuomotor</u> (V) subscale reflect the report of visually-related symptoms such as eyestrain, difficulty focusing, blurred vision, and headache. Finally, scores on the <u>Disorientation</u> (D) subscale are related to vestibular disturbances such as dizziness and vertigo. In addition to the three subscales, an overall <u>Total Severity</u> (TS) score, similar in meaning to the old MSQ score, is obtained. Each MSQ subscale was scaled to have a zero point and a standard deviation of 15.

The significance of the application of this scoring method is evident when the profile or "spectral" composition of simulator sickness symptoms is compared with spectral compositions for other forms of motion sickness. Figure 1 depicts these different profiles for simulator and seasickness. Note that visual problems (e.g., eye strain) are prominent in simulators, but neurovegetative (nausea) phenomena predominate in seasickness and disorientation is minimal in both environs. Therefore, the profile of symptomatology from these two environments show wide disparity and this is not surprising in view of the remarks made by Thornton, Moore, Pool, and Vanderploeg, (1987) who point out the differences between space motion sickness and other forms of motion sickness. Figure 2 compares data obtained from two simulator groups from the U.S. Navy's simulator sickness data base, one group with high and the other with low incidence of simulator sickness. This comparison demonstrates that the difference between these two simulator groups is primarily in visuomotor symptomatology, and points out the requirement for examining the visual stimulus as one of the major determinants of simulator sickness. "Bad" simulators may have twice as much disorientation and nausea, but five to ten times as much visuomotor disturbance.

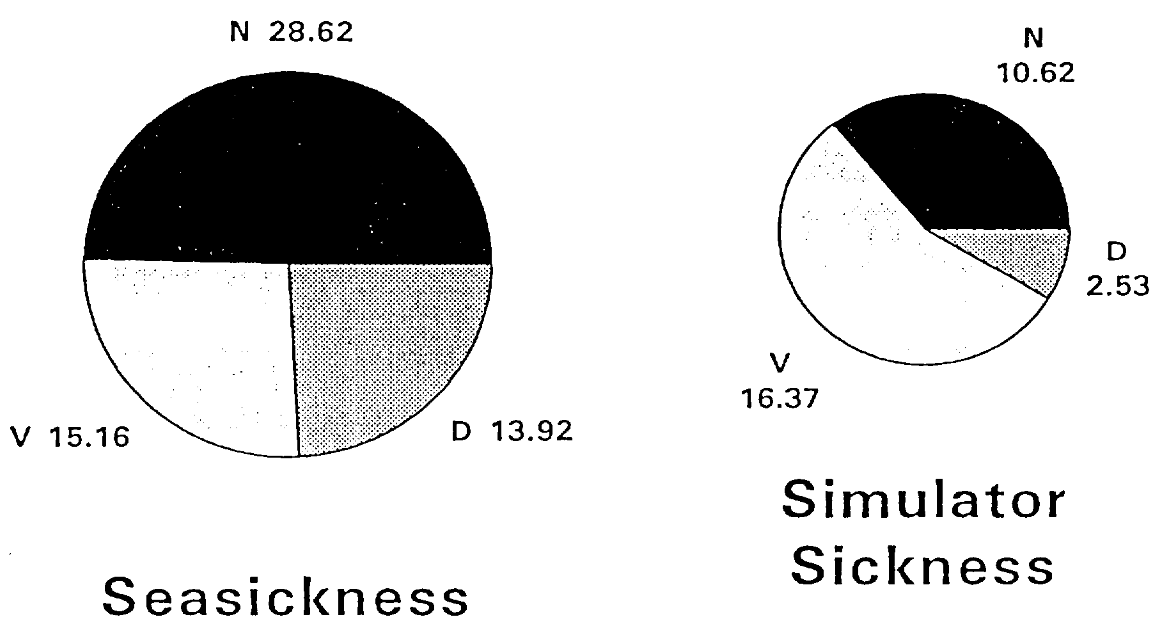

Figure 1. Spectral profiles for seasickness versus simulator sickness.

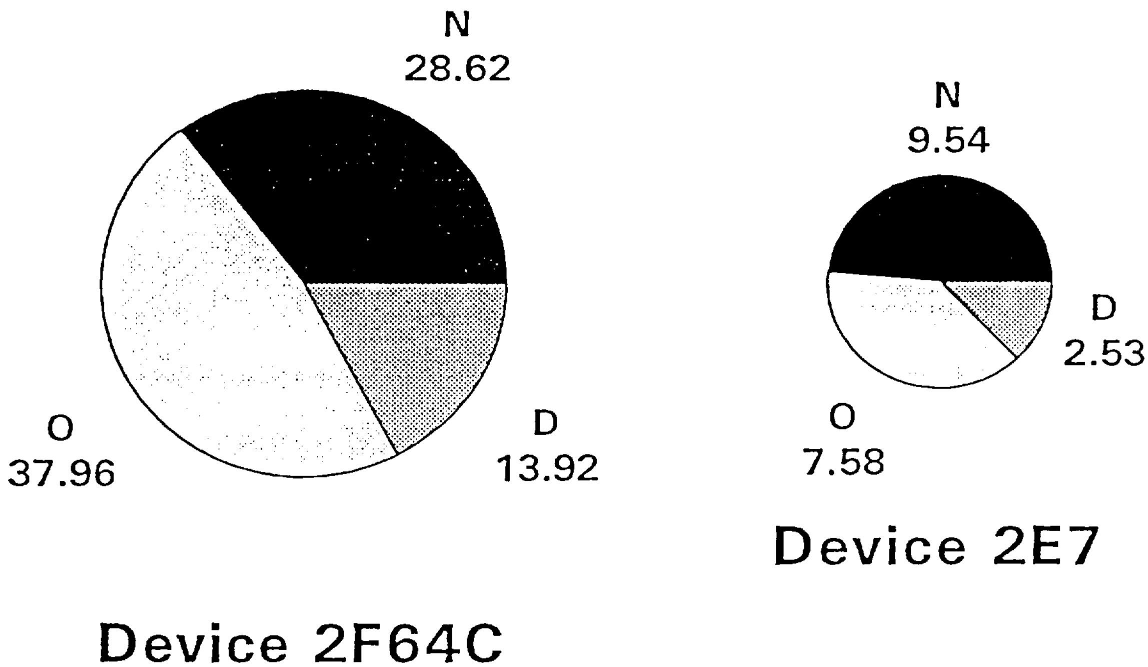

Figure 2. Spectral profiles comparing two Navy simulators.

However, Figure 3 shows two simulators with approximately equal incidence (shown by equal area in the two pie charts), but different distribution of the spectral (i.e., symptom cluster) content.

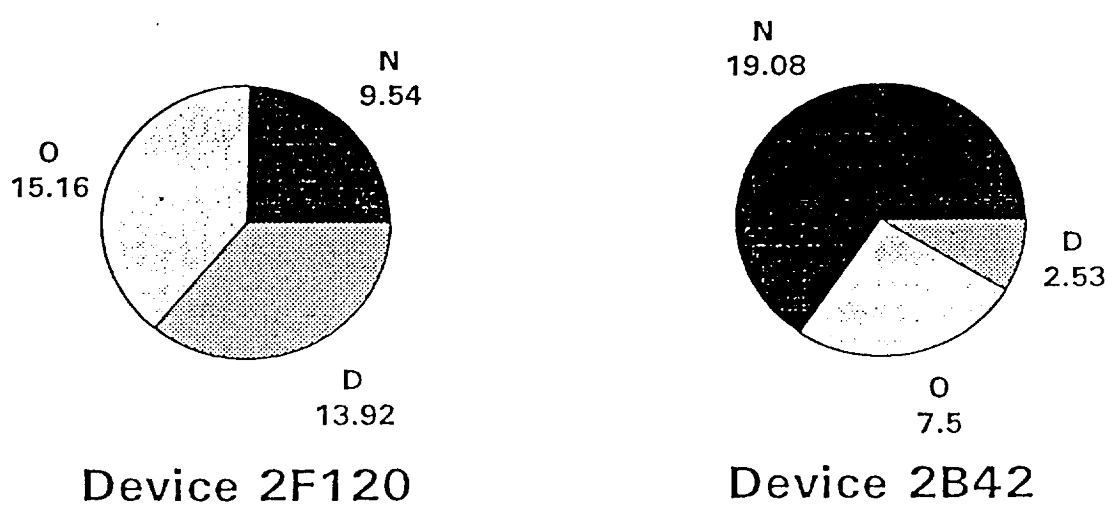

Figure 3. Spectral profile comparing two Navy simulators.

It would be useful to develop a similar profile analysis technique for the study of SAS. The goal would be to identify the separable dimensions of this form of motion sickness and to apply that knowledge to the design and use of the PAT. Initially, it may be wisest to develop the technique using data collected from non-SAS situations (due to the difficulty in obtaining actual SAS incidence data). Eventually, however, we would recommend validating the model with SAS data. Once the technique is fully developed, it can be used to match the dimensions of sickness and disorientation obtained with the PAT to that observed in actual SAS. This would provide two major functions: (1) it would serve as an index of the fidelity of the PAT, and (2) serve the diagnostic purpose of indicating which aspects of the simulation need to be enhanced to provide a higher fidelity representation.

Finally, the literature (>250 references) was synthesized and the information was used in the planning of the empirical and data analytic work.

During the period of performance of this contract, 8 quarterly progress reports were submitted between October 1989 and December 1991, documenting the progress. When compared to original planned efforts, progress was slowed due to reductions in funding received. Specifically, funding remained at <50% throughout the first two years of the project and the project was unfunded in the last 16 months.

Experiment 1

The term "vection" refers to the compelling subjective experience of self-motion that can be induced in a stationary individual viewing appropriate optical specifications of self-motion. It has been widely investigated in the past by many researchers. Experiments have been conducted to assess the effects of various factors on the strength of the illusion, including size of the field of view (eg., Andersen & Braunstein, 1985; Dichgans & Brandt, 1978), stimulus velocity (eg., Lestienne, Soechting, & Berthoz, 1977), spatial frequency (or texture density) (eg., Diener, Wist, Dichgans, & Brandt, 1976; Lestienne et al., 1977), and perceived depth (eg., Andersen & Braunstein, 1985).

Toward this end we have recently completed an experiment designed to assess the stability and reliability of three measures of circular vection: latency, slope of the latency curve across the values of stimulus velocity tested, and the intercept of the latency curve. The goal of the research was to determine whether the phenomena was stable enough to be reliably produced in individuals. If so, further research would be justified to explore making use of this illusion to produce a pheonomenal experience and symptomatology similar to that of SAS, and thereby promote adaptation to the syndrome prior to flight.

Method

Subjects were 22 undergraduate students from the University of Central Florida who were paid for their participation. The device used in this experiment to induce an illusory sensation of circular self rotation was a cylindrical vection drum six feet in diameter with a height of six feet. The drum was suspended from the ceiling such that the open ends were parallel to the ceiling and floor. On the inside surface of the drum were arranged alternating black and white stripes, six inches in width. The bottom end of the drum was approximately 2.5 feet from the floor.

A platform was mounted inside the drum that was elevated approximately 1 foot from the floor. A chair was mounted on the platform such that the observer's eyepoint was centered relative to the diameter of the drum. Attached to the chair was a hand-held switch that was used by subjects to indicate the onset of vection.

Upon entering the vection drum subjects were instructed how and when to use the vection switch. Subjects were asked to face forward with eyes closed until an overhead light within the vection drum was illuminated. At this point subjects were told to open their eyes and gaze directly at the rotating inner surface of the drum until such time as illusory circular self motion began to be experienced. If no such illusory self motion was reported, the trial continued for 90 sec and then ceased. If illusory self motion was experienced, subjects indicated so by operating the hand-held switch. At that moment the overhead light was extinguished and the motion of the drum ceased. Subjects then closed their eyes until the beginning of the next trial.

In addition to the above task, subjects were also asked to estimate the angular velocity of the drum. Prior to the initiation of testing, subjects were shown drum speeds of 20, 110, and 210 deg/sec. Subjects were correctly informed of the drum speeds and were told that part of their task would be to perform similar estimates for each trial in the experiment. During the experiment, subjects gave verbal estimates of drum speed immediately following the cessation of each trial.

Subjects observed drum velocities that varied between 20 and 210 deg/sec in 10 deg/sec intervals. Therefore, a total of 20 different drum velocities were used, each velocity presented twice per session for a total of 40 exposures. Order of presentation of drum velocity was randomized for each session. Subjects performed the experiment on each of five consecutive days.

Results

On the initial day of testing all subjects reported the onset of illusory rotational self motion less than 30 sec following stimulus onset. However, across the five days of data collection a trend was observed which indicated that subjects whose latencies were on the order of 10 seconds or less maintained a consistent latency profile. That is, their latencies remained essentially identical from one day to the next (Figure 4). A second group of subjects with longer initial latencies (between 10 and 25 seconds) showed increased latencies across the remaining four days of the experiment. These results indicate that those observers who were initially more sensitive to the perception of illusory self rotation remained so throughout the experiment, while those subjects whose initial latencies were comparatively longer became less sensitive to the illusion.

Among this second group of subjects, three showed an increase in latency from the first to the third session, followed by a decrease in latency through the fifth day. In two of these cases, the latency observed on the fifth day was less than that observed on the first day. The remaining five subjects in this group showed a fairly consistent trend indicating increased latency across all five days.

Correlational analyses demonstrated significant relationships between average latency measures across all five days, indicating that these data are, on the average, highly stable. However, the presence of separate trends in the data indicate that this stability is largely a function of those subjects whose latencies remained fairly constant throughout the entire experiment.

Effect of Stimulus Velocity on Response Latency

In general, response latency varied with the presented stimulus velocity as a U-shaped function. At the slowest stimulus velocity presented (20 deg/sec) latency averaged 17 deg/sec. This value decreased in an approximately linear fashion with increases in stimulus velocity up to 90 deg/sec. Latencies remained in the neighborhood of 11 seconds for stimulus velocities between 90 and 150 deg/sec, and subsequently increased with values up to 210 deg/sec, the highest velocity tested. These findings are consistent with studies using smaller devices and fewer sessions (e.g., Dichgans & Brandt, 1978).

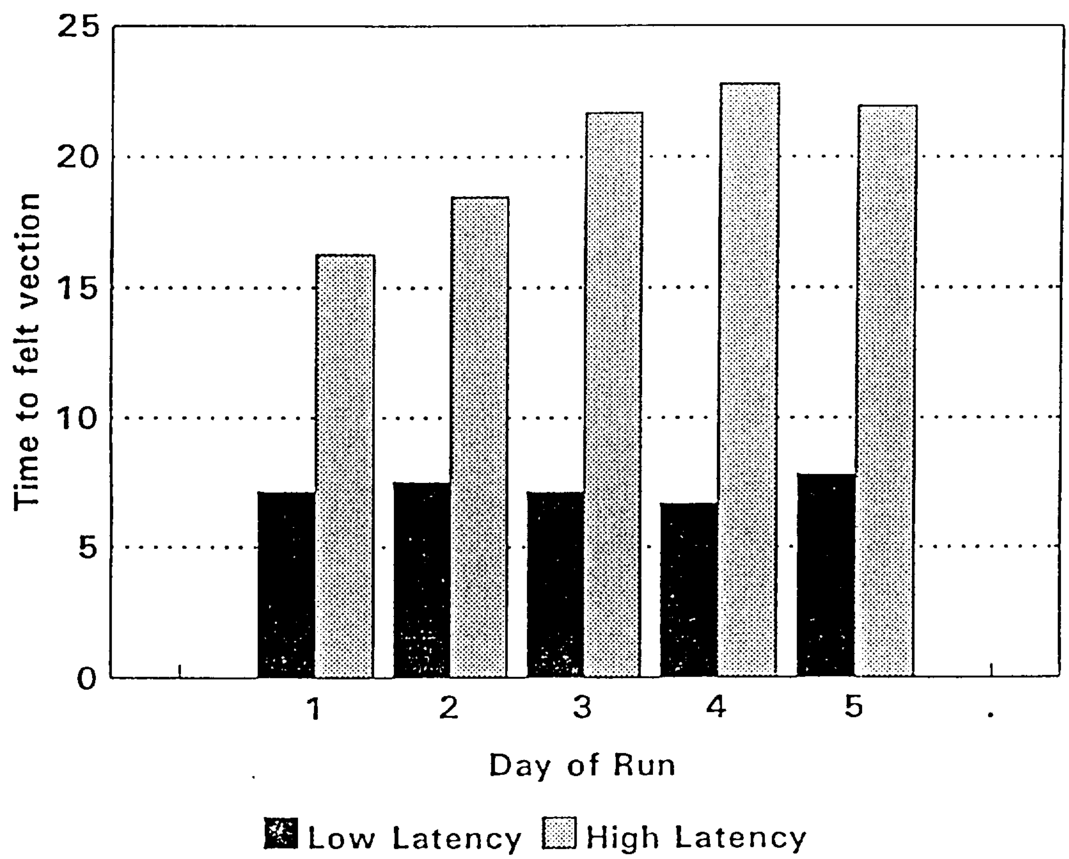

Figure 4. Average mean latency in perception of vection over five days for low and high latency subjects.

As with other perceptual phenomena, large individual differences were noted for latency as a function of stimulus velocity. Approximately half the subjects tested showed minimal fluctuation in latency values. These subjects' latencies remained largely invariant (on the order of 5 to 10 sec) for all stimulus velocities used. The remaining half of the subjects produced latencies consistently above those of the first group. This group's latencies more closely approximated the U-shaped function. These individual differences appeared to be reliable. It is probable that some of these individual differences may signal sensitivity to other forms of apparent motion.

Slope. Individual slopes for the curve representing latency as a function of experiment day were caculated. Combined scores for all subjects represent a general increase in the slope of the function across the first four days of the experiment, followed by a decrease on the fifth day (see Figure 5). As with previously discussed results, inspection of individual slope scores indicate that subjects were divided into two groups, those whose slopes remained fairly constant throughout the experiment and those whose slope scores increased substantially.

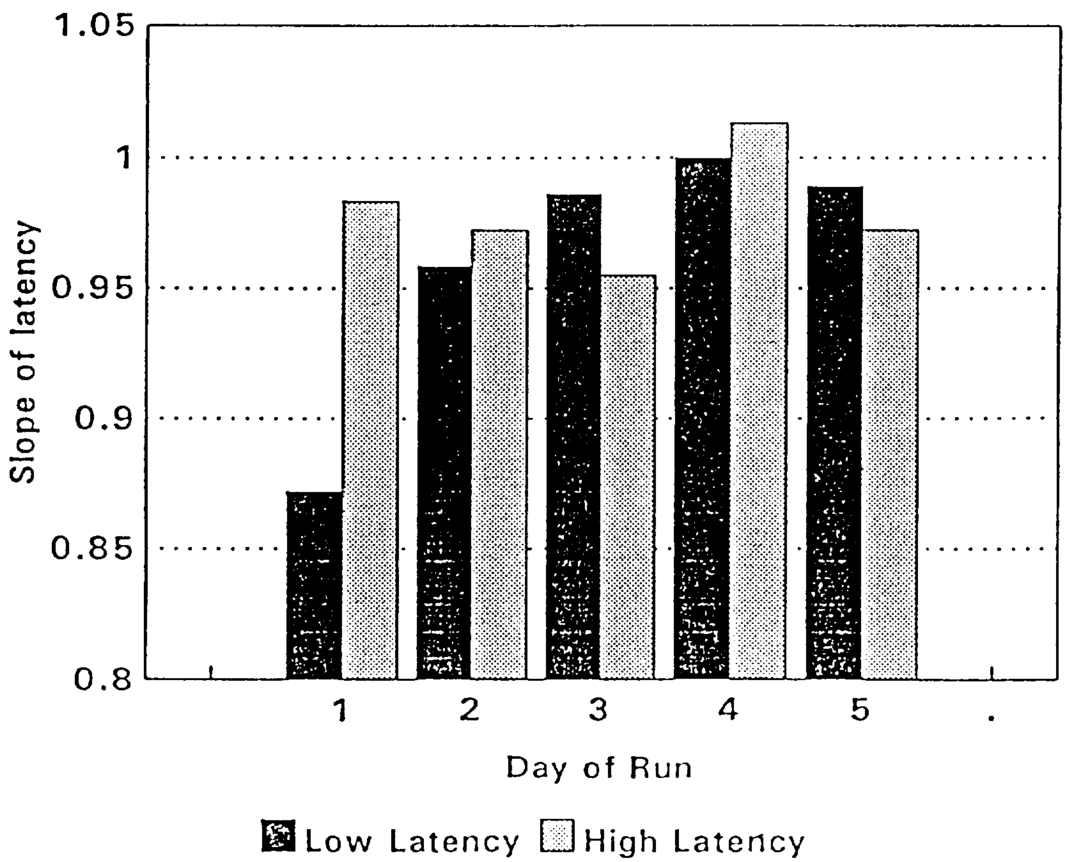

Figure 5. Average slope latency in perception of vection over five days for low and high latency subjects.

Individual intercept scores for the curve representing response latency as a function of experiment day were calculated. Combined scores for all subjects indicate that the average intercept value increased in a roughly linear fashion across all five days (Figure 6), although variability between individuals was very high. There were no consistent trends observed among subject subgroups.

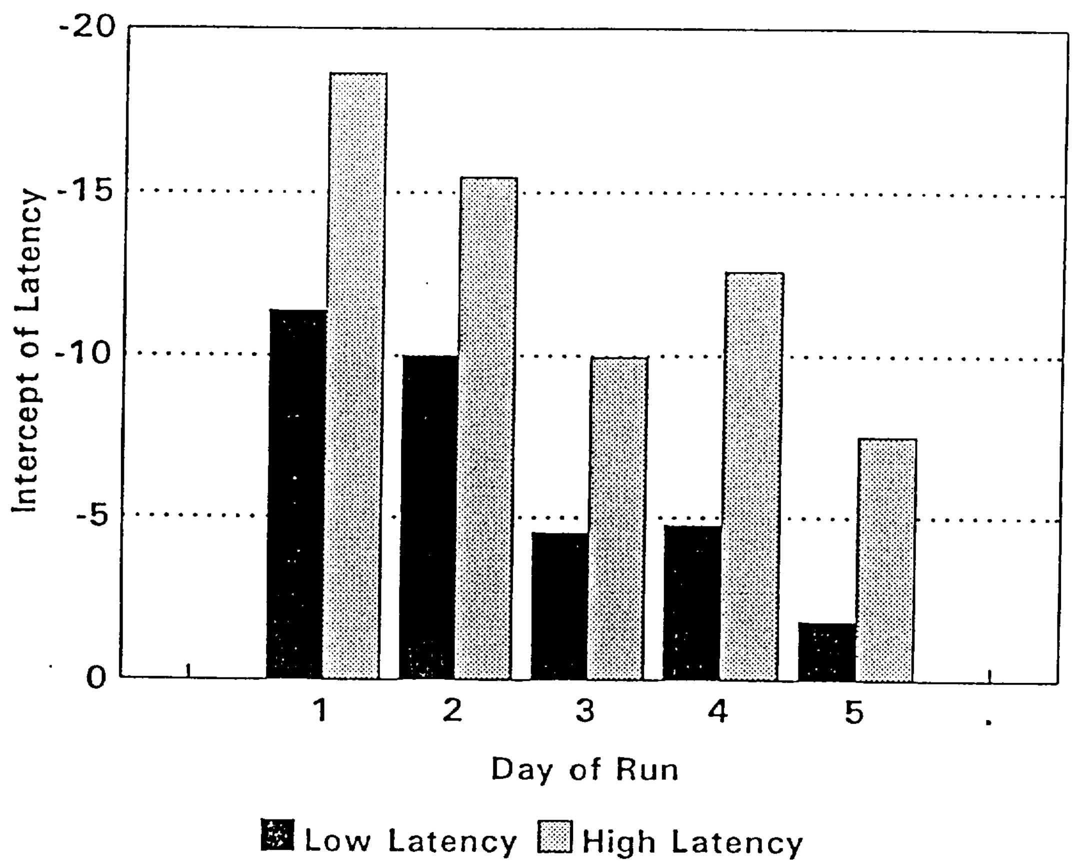

Figure 6. Average intercept latency in perception of vection over five days for low and high latency subjects.

Apparent Velocity. Results for subjects' estimates of apparent drum velocity indicated a consistent tendency toward underestimation. While substantial individual differences were present, it is interesting to note that overestimates of drum velocity were rare in comparison to underestimates.

Discussion.

Implications of vection experiment. An experiment was conducted to assess the stability and reliability of three measures of sensitivity to circular vection: latency, slope of the curve relating latency to all values of stimulus velocity tested, and the intercept of this curve. The results indicated that one of these measures (latency) demonstrated a great deal of stability across the five days of the experiment even though substantial individual differences were observed. Specifically, one group of subjects produced initial latencies that were low (on the order of 10 sec) and which remained low throughout the duration of the experiment. A second group produced initial latencies that were higher (on the order of 15-30 sec) and which then tended, on the average, to increase across subsequent test days. The results for the slope measure indicated a similar two-way split, but were less stable. The results for the intercept measure showed moderate stability over sessions.

The implications of these results for the use of the PAT lie primarily in the finding that measures of vection latency, though apparently subject to group differences, are nonetheless highly stable. While vection has been previously demonstrated to be critical for the development of motion sickness symptomatology in flight simulators (Hettinger et al., 1990), there has been no evidence presented to indicate whether the vection percept is stable, i.e., whether its phenomenal characteristics remain constant across repeated exposures.

Indications that these characteristics are stable are encouraging in that we may now begin to identify the stimulus factors that control the phenomena in order to reliably produce it. The ability to produce the vection illusion may prove to be critical to the goals of the PAT in that it is a known precursor of motion sickness in fixed-base simulators. It will now be possible to use the stability of the vection threshold and transfer function data as a way of equating individuals in perceptual adaptation studies. It is well known that cross-coupled angular accelerations (often involving gyroscopic torques in the semicircular canals) can produce symptoms of motion sickness and in one form or another such stimulation is used in laboratories in tests of motion sickness susceptibility. "Coriolis" is the term usually applied to refer to these cross-coupled accelerations (and their effects). During vection it has also been reported that a form of Coriolis experience occurs (called pseudo-Coriolis since it occurs in the absence of a physical rotatory motion). Motion sickness is reported during these experiences. As with motion sickness induced by Coriolis stimuli and with space sickness, the pseudo Coriolis symptoms diminish with repeated exposure and adaptation permits increased tolerance to subsequent exposures. Arguably such a set of stimuli could serve as a model in which to examine the perceptual adaptation process to motion sickness from all causes. Following this logic, now that we have demonstrated the stability and reliability of the simple vection stimuli, we propose to conduct a series of experiments using pseudo-Coriolis produced to a vection drum to determine the individual differences in adaptation as well as the rules for transfer of perceptual adaptation (acquisition, saving, extinction, transfer of training, generalization, etc.).

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